COAL AND CARBON IN THE POST-PETROLEUM WORLD

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INTRODUCTION: The petroleum age, which we now enjoy, and which makes possible the luxuries, comforts and necessities of our modern world, will not last long. As has already happened in the United States, the ability of the world to produce oil will fail to meet the market demand. The U. S. dodges this problem at present by importing nearly one-half of its oil. In the future the world has scant chance of importing oil from the moon, from Mars, or anywhere else.

The coal deposits of the world are some 100 times as big as the original oil deposits. There was a coal age which preceded the petroleum age. It was associated with the industrial revolution. Iron was made in large amounts by the use of coke from coal. Steam engines using coal drove railroad locomotives, ships and factory engines. Cities were lighted and heated with coal gas. Coal is now used only to make coke and for the generation of electricity. This last market causes air pollution or "acid rain".

Technology exists (pioneered in Germany by Bergius and Fischer-Tropsch in 1920-45) for the conversion of coal to gasoline and diesel oil. This technology was used by US industries and the government in the period 1974-82 in an attempt to make mobile motor fuel using coal as the resource base. This commercialization failed utterly. The conversion of coal to gasoline and diesel yields scarcely more than one-third of the coal's energy in useful products. In addition, the investment and operating costs of these conversion plants are some 15 times as expensive as petroleum refineries. (Gaensslen 1979)

This paper proposes that coal be used to supply mobile motor fuel by a different method. Pure carbon (Boudouard Carbon) is made as a major product from the coal. This carbon serves to replace gasoline, diesel oil and jet fuel.

<u>Refinery Block Diagram: Post-Petroleum World</u> (Figure 1): The future coal refinery will use coal as the raw material. Coal will also be supplemented by shale oil, tar sands and residual petroleum oil.

The coal will be coked in staged, fluidized beds with oxygen for partial combustion to supply the needed heat directly. This section, in addition to coke, will make a good grade of crude oil and sulfur as co-products. Part of the hydrogen-rich gas product is used to up-grade the volatilized hydrocarbons into a synthetic crude oil. The major product is powdered coke (Bloom 1977). The product coke, after briqueting, is transferred to the main section of the coal refinery.

Briquetted coke is gasified in a slagging-ash gas producer using air as oxidant and CO2 as reductant gas (Ermankov 1957). The CO and H_2S of the producer gas are separated together from the N_2, CO_2 and H_2 (small) by a solvent (Walker 1987) (Bartish 1983). H_2S is converted into product sulfur in a Claus plant while the CO is converted into CO_2 and Boudouard carbon product. (Donald 1956). The large reaction heat of the Boudouard reactor is used to make electricity as an additional product of the refinery.

Coking Section of the Coal to Carbon Refinery (Figure 2): This follows exactly the COED process which was developed by the FMC corporation and the Office of Coal Research (1960-75). (Bloom 1977). All kinds of coal can be used in this process. The temperatures of the stages of coking are somewhat different with different coals. The amount of oil produced varies from 1 to 1.5 barrels per ton depending upon the coal's volatile matter content. A minor amount of hydrogen-rich gas is available for other uses.

This coking has never been used on large scale commercially. Because the sulfur content of the coke product is just as high as that of the coal feed, the coking must be justified by the difference in price between the oil product and the coal feed. Contemporary price ratios of coal and oil are not yet different enough for this process to be economically viable as long as the coke is simply to be burned in the conventional generation of electricity. However, as is the case of this present proposal, if the coke is used to make a major high grade motor fuel, the economics will be quite different. This coking also has the desirable property of making the available hydrogen content of the coal into liquid hydrocarbons. While not of interest at the present, this can be of immense important in the future when there is no petroleum left. All of the future petrochemical industry might be supplied by this coal refinery side-product: The much larger mobile motor fuel market, at that time, would then be supplied by carbon.

Coke to Carbon Section-Coal to Carbon Refinery **(Figure 3) (Hadley-Coates 1988)** : Process Description: Coke is fed to a fixed bed slagging-ash gasifier fed with hot air as oxidant and hot CO_2 as reductant gas(Ermankov 1957). Tar and pitch are absent from the producer gas. The sensible heat of the gas is used to generate stream. The cooled gas is dedusted and stringently dried. A separation solvent next quantitatively catches the CO and H_2S content of the gas after which the residual gas is exhausted to the atmosphere (Walker 1987 and Hadley-Coates 1988). The mixed CO and H_2S stream is regenerated from the solvent and then fed to an aqueous ethanolamine solvent unit to quantitatively separate the H_2S from the CO. The H_2S is fed to a Claus plant and converted quantitatively into product sulfur. The pure CO is converted into CO_2 and product carbon in a Boudouard reactor at 500-25 C (Donald 1956). Hot CO_2 is recycled to the gas producer. The temperature of the Boudouard reactor is maintained by evaporating a high temperature organic solvent within heat exchanger tubes. The gaseous organic is then fed across a turbine to generate electricity . The low pressure organic gas from the turbine is condensed in process reboilers at 150 C and recycled to the Boudouard reactor. The process reboilers are used with the separation solvents to catch CO + H_2S and to separate H_2S from CO.

Carbon as Motor Fuel (**Figure 4**) : Diesel engines were run for many years in Germany in a large scale development program(1910-45). This program used coal dust as the motor fuel. Many devices were developed to feed the coal dust into the engine with successful results. One such device, used by the Germans, is shown at the top of figure 4.

The coal dust engine failed to be commercially successful because of two reasons. The ash content of the coal caused unacceptable wear rates on the cylinder walls, rings and piston heads of the engine. Coal dust, as ground in practical grinders, contains too many large particles. These will not burn up completely in the short times available in a diesel engine. (Soehngen 1976)

Boudouard carbon is completely ash-free ! In addition, the intrinsic particle size of Boudouard carbon is very small (Watanabe 1929); much smaller than can be obtained than by grinding large solids into powders. (Soehngen 1976). The particle size of Boudouard carbon is small enough to burn completely in a high speed Diesel engine (Essenhigh 1979).

Otto-cycle engines compress a fuel mixture of fuel and air and then fire it by an electric spark. Some early engineers once ran a model A car successfully on flour by means of a dust carburetor! Nowadays some cars use injection methods to mix air and gasoline instead of a carburetor. Otto-cycle engines can be made to work on solid and non-volatile fuels like pure carbon.

The turbine-cycle engine is shown diagrammatically. In a turboprop airplane the propeller is tied to the power coupling. With jet planes the hot combusted pressure gas propels the plane directly. This type of engine, while not as efficient as the diesel, puts out a great deal more work per given engine weight. For airplanes this is a decisive advantage. It is also a simple engine which can run for millions of miles in its lifetime provided that the fuel used is very clean.

Boudouard carbon is fine grained and entirely free of ash, pitch or tar. (Watanabe O. 1929)

Yields and Costs of the Coke to Carbon Part of the Coal to Carbon Refinery: The overall reaction of the gasifier is approximated by:

$$1.5\ C + 1\ CO_2 + 0.5\ O_2 + 2\ N_2 = 2\ CO + 2\ N_2 + 0.5\ CO_2$$

The yields of the process (based on energy of the coke fed) are estimated to be:

Boudouard Carbon	70 %
Electricity	8 %
Useful Product Yield	78 %

Using Gaenslen's (1979) methods, it is estimated that a coal to carbon refinery will require less than one-third the investment and operating cost of present technology to convert coal to gasoline and diesel oil (Hadley-Coates 1988). It will also make twice the yield of useful products.

Final Thoughts: A new technology is possible which uses coal to make Boudouard carbon as a major product. This product can, in the future, supply most of the mobile motor fuel requirements of the world. New directions are required in research and development in order to make this technology a practical reality. I hope that this paper will stimulate many of you to enter this vital and important field of endeavor. You can help to make both it and yourselves successful.

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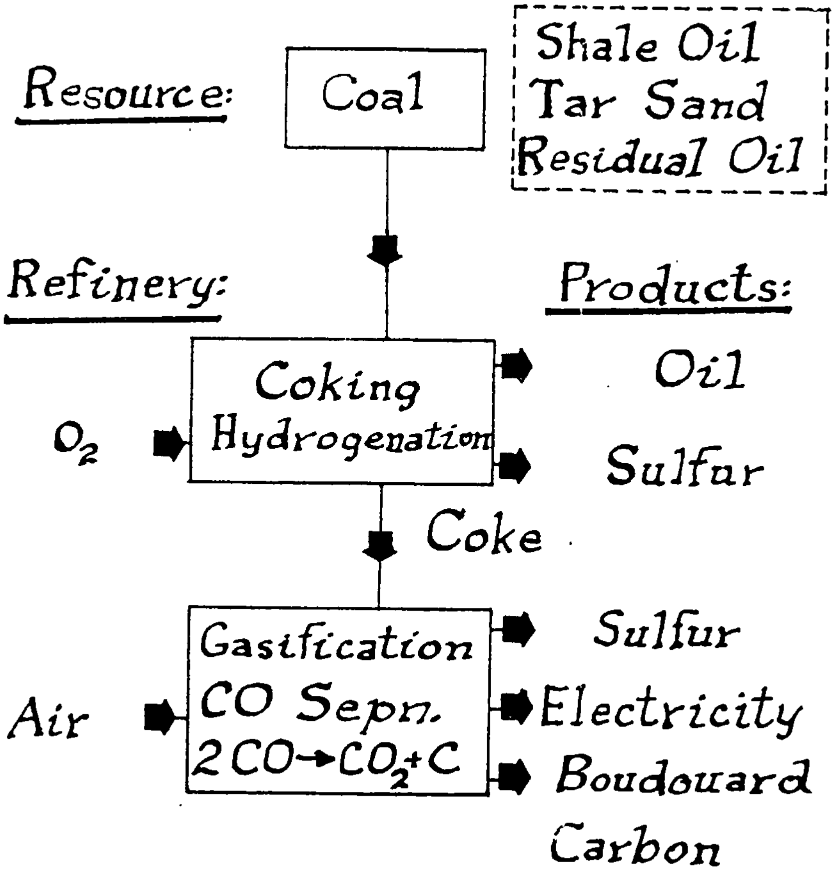
FIGURE 1



POST-PETROLEUM ECONOMY

FIGURE 2

Coal to Coke-Oil-Hydrogen: COED Process

FMC Corp. and Office of Coal Research

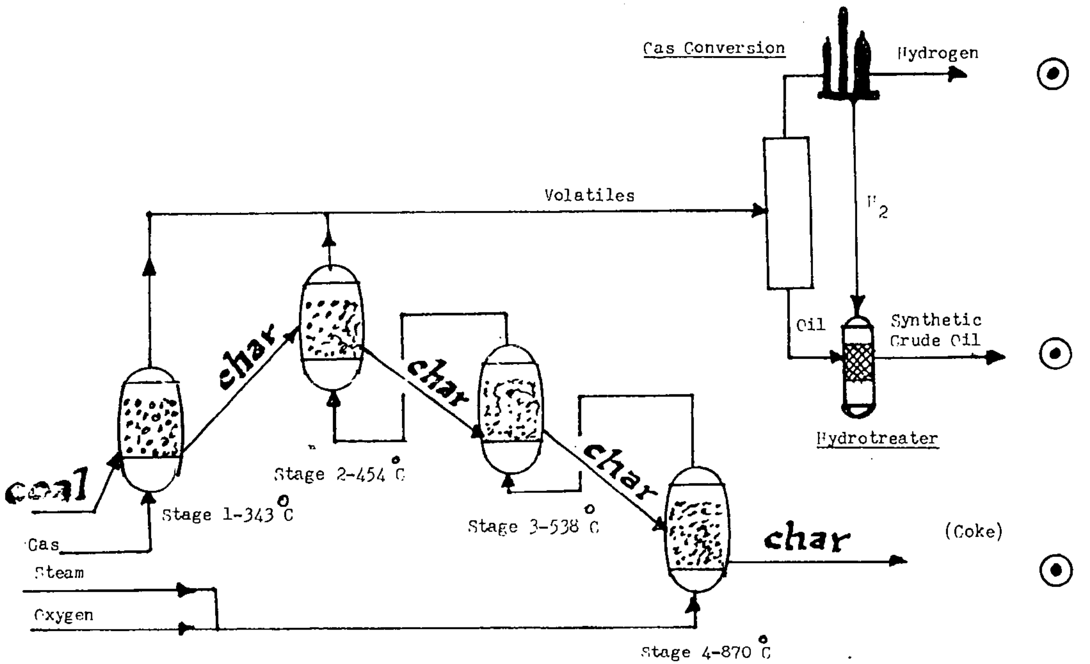
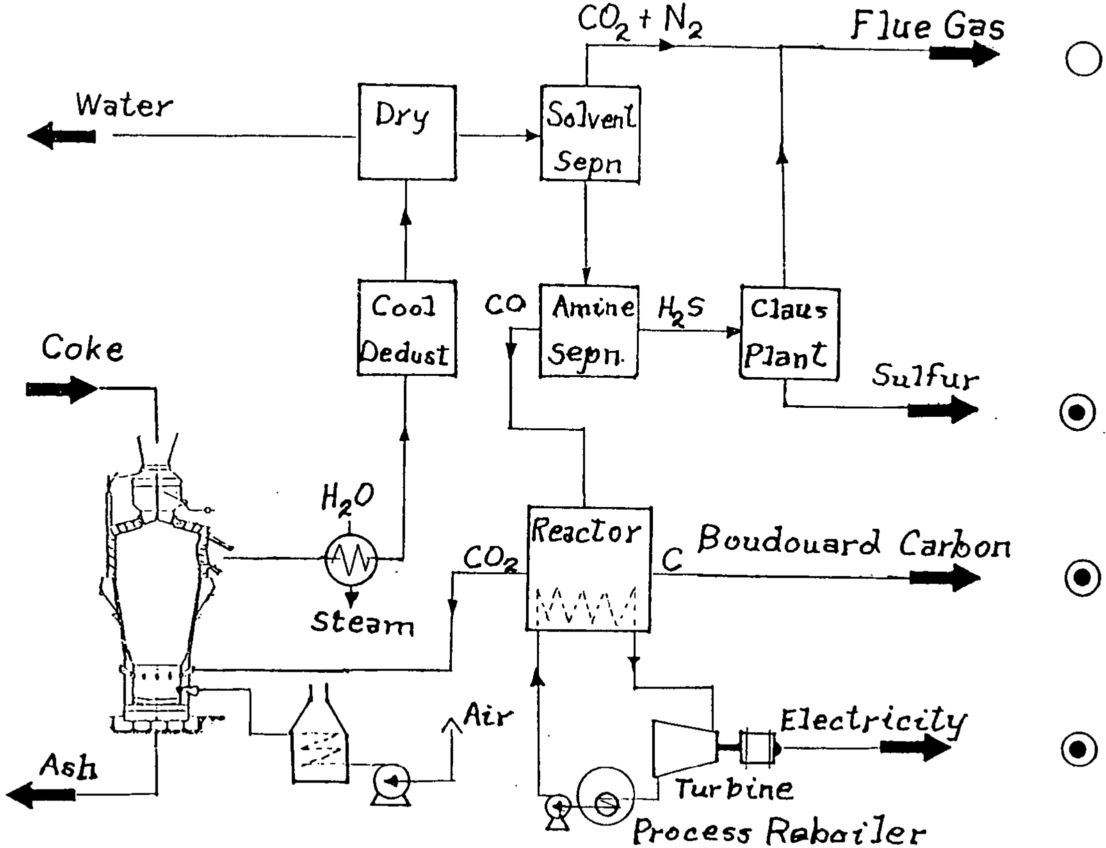


FIGURE 3



COKE TO CARBON REFINERY

Diesel Engine

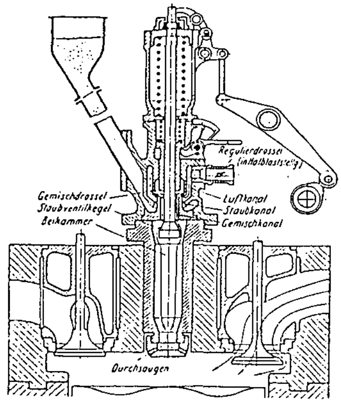
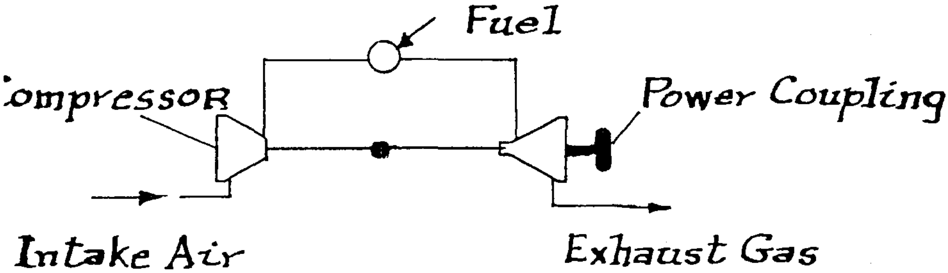


Abb. 304. Schematische Darstellung der pneumatischen Staubeinschleusung nach dem Verfahren NÄGEL-ZINNER.

Otto Cycle Engine

Turbine Engine



CARBON AS MOTOR FUEL

FIGURE 4